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FIBRE BRAGG GRATING SENSORS FOR RADIATION INSENSITIVE MEASUREMENTS

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Paper Summary
The response of fibre optic-based sensors exposed to gamma radiation is presented. This study shows that suitable fibre Bragg grating sensors exhibit a saturated radiation induced shift < 20 pm after 16 MRad of exposure.

Introduction
Electronic and photonic components are well known to suffer from exposure to ionising radiation [1]. The radiation interacts with the materials, alters their characteristics and most often modifies the performance and reliability of the device. Resulting device failures and system malfunctions may have dramatic consequences on safety and carry significant financial repercussions.

Several years ago optical fibres carried a relatively bad reputation in terms of resistance to ionising radiation. Fibres were known to darken rapidly during exposure with substantial levels of so called radiation induced attenuation (RIA) as a result. Modern commercially available fibres now exhibit low to moderate levels of RIA. This, together with the undeniable advantages of fibre optic technology and the increased availability of compact, efficient and lower cost devices, has renewed interest in the applications of optical fibre based systems in radiation environments.

The primary interest of this paper is the use of Fibre Bragg Grating (FBG) sensors for radiation insensitive measurements (temperature and/or strain for example) in nuclear and space environments. In particular, a comparative study of FBGs written in a variety of optical fibres using different fabrication techniques and their response to gamma radiation will be presented.

Experiment
A list of the commercially available fibres used in this study and the types of fabricated sensors are shown in Table 1. Type I and Type IIa FBG sensors were interferometrically written into photosensitive fibres using the phase mask technique [2]. Uniform fused silica phase masks (QPS Photronics Inc.) and a 248 nm (UV) KrF excimer laser system (ATLEX-300-SI) were utilised for this technique. Type II FBG sensors were inscribed into fibre cores in a point-by-point (PbP) fashion using ultrashort laser pulses [3]. This method of fabrication incorporated an 800 nm (IR) pulsed femtosecond laser (Spectra-Physics Hurricane), a fixed glass ferrule and a translating fibre configuration [4]. The advantage of this technique is that the fibre core does not need to be photosensitive. Fibres were stripped before fabrication and all FBG sensors were created such that their Bragg resonance lay within the C-band (1520-1570 nm).

Fibre	Fibre Specs	FBG Type	Fab λ
Fibercore PS1250/1500	-Boron doped -Photosensitive	I	UV PM
Fibercore SM1500	-Highly germanium doped -Photosensitive	I	UV PM
Nufern GF1b	-Germano-Fluorosilicate -Photosensitive	I	UV PM
Fibercore PS1250/1500	-Boron doped -Photosensitive	IIa	UV PM
Corning SMF 28e	-Standard single mode	II	IR PbP
Fibercore PS1250/1500	-Boron doped -Photosensitive	II	IR PbP
Nufern R1310-HTA	-Radiation Hardened	II	IR PbP

Table 1: Commercial fibres, sensor types and fabrication parameters used in this study. PM – Phase Mask, PbP – Point-by-Point.

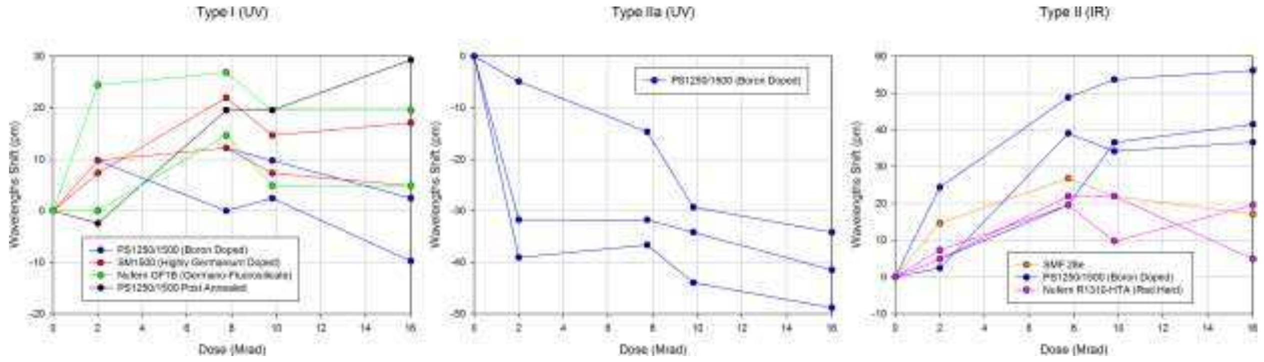

Figure 1: Radiation induced Bragg wavelength shift for different FBG sensor types with respect to gamma radiation exposure. Left to right: Type I (UV), Type IIa (UV) and Type II (IR).

The FBG sensors were exposed to ionising gamma radiation, typical of that found in nuclear environments, to establish which combination of fibre and fabrication technique would work best to create radiation insensitive optical sensors. A Cobalt-60 source with a gamma radiation dose rate of 3.88 kGy/hr (0.388 Mrad/hr) was used to expose FBGs up to a total dose of 16 Mrad. Samples were removed from the gamma radiation chamber 5 times for analysis. The Bragg wavelength shift of each exposed FBG sensor was captured using a Micron Optics SM125 sensing interrogator unit. All FBG sensors were fixed in place during experimentation so as not to experience a Bragg wavelength shift due to strain. Data was temperature compensated using an unirradiated FBG sensor during analysis.

Results

Firstly it is important to note that all the FBG sensor reflectivities stayed strong throughout the experiments. No noticeable intensity drop was seen. All experimental exposure results are shown in Fig. 1.

Type I (UV)

Type I FBG sensors showed on average < 20 pm red shifts at saturation from their initial values. Peak shifts seemed to saturate beyond 8 Mrad. Literature shows that this 20 pm shift towards longer wavelengths is the usual trend for Type I FBGs [5,6]. Figure 1 shows no clear advantage of using any particular fibre for Type I FBG sensors. In fact, the induced shifts shown using the same fibre were sometimes more than 15 pm apart at a given dosage. This is due to the fact that the Type I FBG sensors in this study were unfortunately not all created on the same day, therefore fabrication parameters varied. The black curve shows that post-annealing FBG sensors (at 200^{o}C for 2 hours) after fabrication and before exposure may lead to a higher saturation dose value which is counterproductive to the aims of this study.

Type IIa (UV)

Type IIa FBG sensors exhibited large blue shifts due to gamma ray exposure. These shifts were > 30 pm and had not reached a saturation level even at a dosage of 16 Mrad. Type IIa radiation induced shifts towards shorter wavelengths has been previously demonstrated [7]. The Type IIa FBG sensors studied here are clearly not suitable for radiation insensitive purposes.

Type II (IR)

All Type II PbP FBG sensors shown in Fig. 1 exhibited a red shift due to exposure and reached a saturation level after 9 Mrad. Of this set, Nufern's radiation hardened fibre is the most suitable for sensing purposes as its red shift averaged < 15 pm and it possess the lowest RIA compared to its counterparts.

Discussion

This study has shown that the FBG characteristic peak wavelength changes due to ionising radiation. The magnitude and direction of this change is very dependent on the FBG sensor type, the host fibre and the fabrication technique. In order to draw solid conclusions, FBG sensors of one Type must be fabricated with identical parameters; this was not the case for the Type I sensors in this study. Furthermore, radiation experiments should be conducted in-situ with continuous real-time monitoring of sensor characteristics. In this study samples were removed from the radiation chamber for analysis which not only limits the amount of data that can be taken but also its reliability. Experimental planning into rectifying these factors is ongoing.

Conclusions

From this preliminary study, it was demonstrated that either Type I FBG sensors created in photosensitive fibre or Type II PbP FBG sensors fabricated in Nufern R1310-HTA radiation hardened fibre would be best suited for radiation insensitive studies. Further, more controlled studies are required to confidently choose between these sensor types. Once determined, such sensors could be used in future projects where ionising radiation is present to analyse, for example, the parameters of temperature, strain, pressure, humidity etc.

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